

Peak RF and Microwave Power Measurements

Application Note Number AN26

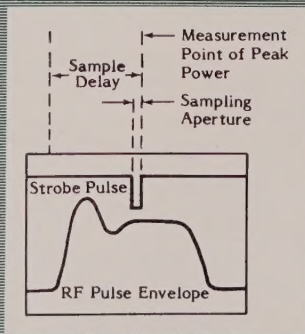
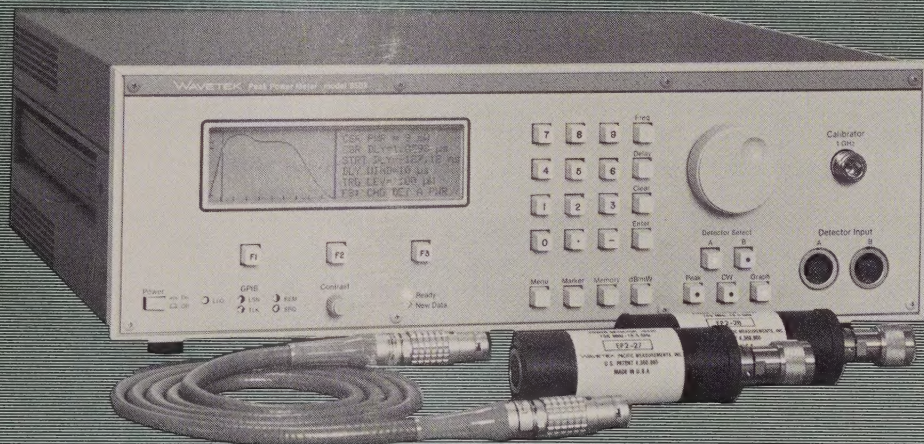


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PEAK RF AND MICROWAVE POWER MEASUREMENTS

INTRODUCTION

The accurate measurement of peak power is vital to assure the proper operation of certain microwave systems and components. Some of these systems in general use today include pulsed radar, TACAN, IFF, and their associated components such as amplifiers and RF sources.

Peak power is usually associated with large power ranges where every dB increase in power level can be very costly in terms of increased complexity of design, cost of components, manufacturing skill, and decreased reliability. These factors dictate that the accurate and efficient measurement of power should be of prime importance. The measurement equipment must have the highest possible accuracy and repeatability, be traceable to a National Standards Laboratory (NBS), be reliable, and be easy to use. The more accurate and repeatable the measurement equipment, the smaller the error budget required for the design, development, and manufacturing of a complex, high power system, and the greater the savings in both time and money.

DEFINITIONS

Average Power

The most commonly used power measurement is "Average Power". Average power means the energy transfer rate is to be averaged over many periods at the lowest frequency of interest. For a CW signal, the highest and the lowest frequencies are, of course, the same. For amplitude or pulse modulated signals, the power must be averaged over many of the modulation cycles. The long thermal time constant of a thermistor or thermocouple power meter performs this task automatically.

Pulse Power

Pulse power readings are taken by averaging the energy transfer rate over the pulse width "t". Pulse width "t" is considered to be the time be-

tween the 50% amplitude points. The definition of pulse power has been extended to be:

$$P_p = P_{ave} / \text{Duty Cycle}$$

where duty cycle is the pulse width times the pulse repetition frequency. Pulse power averages out any aberrations in the pulse such as overshoot or ringing.

A thermistor or thermocouple power meter measures the average power, and the reading is converted to peak power when divided by the duty cycle. This method assumes that the pulse envelope is perfectly rectangular; therefore, the readings are in error if any aberrations are present in the pulse shape. These errors are compounded the more the pulse shape differs from the rectangular shape (such as Gaussian -- see Figure 3 on page 4).

Peak Envelope Power

Envelope power is measured by setting the pulse averaging time to much less than $1/f_m$ where f_m is the maximum frequency component of the modulated waveform. The averaging time is therefore limited on both ends: (1) It must be small compared to the period of the highest modulation frequency, and; (2) It must be large enough to be many RF cycles long. Peak envelope power is measured at the peak of the pulse.

The Series 8500 meters essentially measure envelope power since they take measurements over a very short (15ns) period. This method can make accurate measurements at any desired point on a pulse as well as giving the ability to evaluate any aberrations or the shape of the pulse itself. This is clearly the most accurate method for making peak power measurements.

Power Sensors

There are three types of sensors normally used to convert RF and microwave power to a measurable dc voltage or low frequency signal. These include the thermistor, thermocouple, and the diode detector. These three detectors

(the diode when used in the square law region), will measure average power when connected to a power meter. When used with a sample and hold power meter such as the Series 8500, the diode detector measures envelope power. A detailed discussion of power measurements using thermistors and thermocouples is given in Hewlett-Packard's Application Note 64-1, "Fundamentals of RF and Microwave Power Measurements". Chapters V and VI of this Note detail the uncertainties of making power measurements when using these thermal devices. Under most circumstances, making accurate power measurements is a very difficult and exacting task.

THE SERIES 8500 PEAK POWER METERS

In designing the NEW Series 8500 Peak Power Meters to replace the old, reliable Model 1018B Power Meter, Wavetek Pacific Measurements (W-PMI) has incorporated the latest state-of-the-art technology to improve accuracy, repeatability, traceability, and ease of use.

The advent of the 68000, 16 bit, microprocessor gave W-PMI's engineers the ability to design new features (such as completely automatic self-calibration) into the Series 8500 that formerly were not possible. It also has allowed most of the functions previously performed by sophisticated analog circuits to be done digitally, thus improving the repeatability of the unit and making it very "user friendly".

A major advancement in the accuracy and NBS traceability of the instrument has been accomplished by incorporating a newly-designed (patent pending) self-calibration system for the automatic calibration of the detector linearizing circuitry in the unit. This system consists of a computer-controlled calibrator circuit which permits the diodes of the detector to be linearized against an internal thermal reference. The NBS traceability is performed by setting the calibrator output to 1mW (0dBm), and checking and adjusting, if required, using an NBS certified thermistor mount and power meter.

The frequency response (calibration factor) information is acquired using a reference thermistor mount as a transfer standard and installed

in a ROM located in the detector head. After the detector is attached and the instrument first turned on, the ROM information in the detector is transferred to an active working memory in the 8500 for use during operation. Measurements taken with these calibrated diode detectors have accuracies similar to commercially available average-reading power meters. Since the 8500 is calibrated using precision CW techniques, and the difference between the CW and Pulse Modes is included in the calibration process, the accuracy of the resulting Peak Power Measurements is the same as that of the CW measurements. (For a complete description of the automatic calibration system, see Appendix A starting on page 7 of this Note.)

The power measurement technique employed in the Series 8500 uses a fast rise time diode detector-amplifier head followed by a sample and hold circuit, analog amplifier, and then digital processing. Techniques employed by other manufacturers use comparatively slow reacting thermistor or thermocouple detector heads. The sample and hold method results in a power meter that measures the power during an extremely short (15ns) period with the measurement completely independent of the pulse width, duty cycle, rise time, fall time, pulse repetition rate, and pulse shape. The action of an average reading power meter used to measure peak power is a function of the interaction of all of these parameters. The problem then becomes the ability to tell the sample gate when to open so that the measurement is taken at the exact point of interest. This is accomplished by a suitable trigger supplied either internally from the rise time of the detected pulse, or externally by using a system timing pulse. Then the sample gate opening is delayed by setting the digital delay generator to the desired delay time. In this way, the measurement can be precisely taken at any desired point on the detected pulse.

In the Series 8500's Graph Mode (see Figure 1), the delay is stepped through a range, readings are taken at each step, and the result displayed on the dot matrix LCD display of the instrument as an accurate reproduction of the RF pulse.

Measuring with the 8500

Taking a measurement with the Series 8500 meters is a very easy procedure. The majority of measurements that are normally required for peak power or CW power testing and evaluation can be made using just the following simple steps:

1. Leave the detector(s) disconnected and turn on the meter.
2. When the prompt on the LCD display asks if self-calibration is desired, connect the detector to the CALIBRATOR output connection and press "Enter". Wait 28 seconds for the self-calibration to complete. If using a Model 8502, repeat the procedure with the channel B detector.
3. After the calibration has been completed, the unit will be in the GRAPH Mode. Simply attach the detector to the measurement port and start taking readings.
4. If peak power readings are desired, press the "Peak" button. If CW readings are to be taken, press the "CW" button.

For many measurements, this is all the setup required. The operating manual for the instrument will describe the procedures for making more detailed measurements.

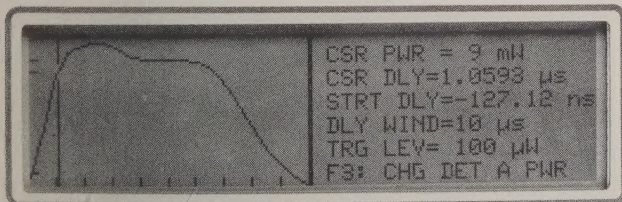


Figure 1. Series 8500 Graph Mode

APPLICATIONS

Radar

The radar signal is normally a repetitive, pulse modulated signal that has a fixed pulse width and pulse repetition frequency. The peak power can be measured using an average power meter

by taking the average power reading and dividing by the duty cycle if it is assumed that the pulse shape is rectangular and has no aberrations. When aberrations such as overshoot and ringing are present, a peak power meter should be used. Since the W-PMI Series 8500 peak power meters use a 15ns sample time, they will take and display accurate readings independent of the effects of the duty cycle, pulse width, rise time, fall time, any ringing, or any other aberrations. All of these factors effect the accuracy of peak power measurements when average reading power meters are used.

Some radar signals use pulse height modulation, and transmit in groups of 2, 3, or 5 pulses per group. One or more of these pulses will be 2 to 4dB lower than the others. The 8500 meter can measure the height of each pulse in the group (serially, not simultaneously). By using the 8500's GRAPH Mode, setting markers at points of interest on the pulses, and selecting the amplitude difference between the markers measurements and/or adjustments of relative pulse heights are easily accomplished.

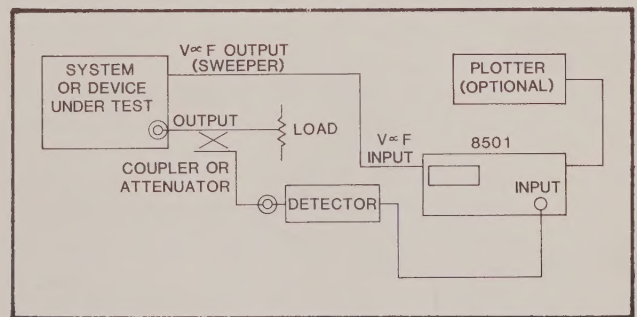


Figure 2. Typical Peak Power Test Setup

A typical test setup is shown in Figure 2. There are several very important precautions that must be observed to prevent the costs and down time that would be incurred by burning out a

detector. The most important of these precautions is the selection of the value of the directional coupler or attenuator used to attenuate high power levels down to a level below the Maximum input measurement level of the detector. The attenuation is calculated based on the Peak power, not the Average power. If the peak power to be measured were 5kW, then an attenuation of 50dB would be required (5kW to 50dB attenuation). If the power were 5mW, then 80dB would be needed. The value of the attenuator can be taken into consideration by entering its exact value in dB using the OFFSET function of the Model 8501 or 8502 meters. This will cause a true reading to be taken and displayed in either Watts, kilowatts or megawatts.

It is also very important to be sure that the center conductor of the coax connector does not carry any large dc voltage that might damage or destroy the detector's diode.

TACAN, IFF, and DME

TACAN, IFF, and DME signals are Gaussian, not rectangular, in shape. The reason this format was used was to conserve the frequency spectrum. Prior to the introduction of the Model 1018 Peak Power Meter by W-PMI in 1969 (then known as just Pacific Measurements, Inc.), this shape (see Figure 3) presented a real measurement problem because the conversion from Average to Peak power was a rather complex operation. The problem was solved with the Model 1018. The 1018 was the first peak power meter to be able to both accurately and automatically read the amplitude modulated Gaussian signals by using a diode detector and sample and hold circuitry.

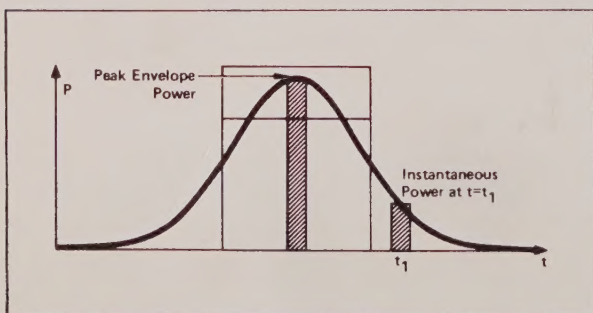


Figure 3. Gaussian Pulse Format

IFF and TACAN signals are also amplitude modulated with the pulse-pair spacing generally of random timing. The Models 8501 and 8502 meters can easily measure the peak power in these signals by using the internal trigger for precise timing along with the appropriate delay to place the sample gate at the peak of the pulse. The unit requires only one pulse to obtain a correct reading. This ability to read a single pulse and also take more than 1000 readings per second allows the unit to measure pulse jitter, which can be of great help for isolating problems in the circuitry of the device being tested.

The Degree of Modulation of the signal can be calculated by using the maximum and minimum power levels (in mW) of the modulation signal. The two power levels are measured by using the GRAPH Mode of the 8500. A marker is first placed at the maximum level, another marker is placed at the minimum level, and the power levels at the two markers are read. Then the following formula is used: (see Figure 4)

$$M = \frac{\sqrt{P_a} - \sqrt{P_b}}{\sqrt{P_a} + \sqrt{P_b}}$$

where: P_a = maximum power in mW
 P_b = minimum power in mW



Figure 4. Modulated Pulsed RF Signal

ECM, ECCM, and EW

These signals are usually complex since both the pulse spacing and/or pulse height are random (there can be 2, 3, 5, or more pulses in a group that have random characteristics). The single pulse, precise delay, fast reading rate, triggering, accuracy, and programmability of the Series 8500 meters makes them the ideal instruments for this application.

ATE

ATE systems require total programmability, repeatability, accuracy, reliability, and fast response from the measuring instrument. The 8500 has all of these characteristics and much more. The self-calibrating feature of the 8500 meters allows them to be used not only as the ideal power meters for both CW and Pulse measurements in the system, but also as reference meters to check the accuracy of other instruments in the ATE system. When used as a secondary reference, the 8500 meters can save costly down time by performing a system calibration check prior to using the system. This means that if any components or instruments in the system are suspected to be the cause of out of tolerance conditions, they can be tested without the necessity of creating down time by having to send them to the calibration laboratory for calibration and/or verification.

Measurements of Rise Time, Fall Time, Pulse Width, and PRF

All of the above measurements are accomplished by using the GRAPH Mode of the 8500, and then setting the cursors to the 10%, 50%, and 90% points on the displayed pulse. Then the instrument is commanded to display the delay difference between and two of the markers. If marker 1 is set at the 10% point, marker 2 set at the 90% point, and the instrument commanded to display Mk1 - Mk2, the result will be rise time. By setting two markers at the 10% and 90% points on the trailing edge of the pulse, the fall time is obtained. If markers are set at the 50% points, the result is the pulse width. If one marker is set at the 50% point of one pulse and a second marker placed at the 50% point of the next pulse, the time difference will be the pulse interval. PRF is defined as $1/\text{pi}$ (pulse interval).

Pulsed Amplifiers and Two Port Devices

Amplifiers and other two port devices that operate only in a pulsed condition can be tested either on a point to point basis or on a swept basis using the Model 8502. The input to the device either can be pulsed RF or a CW signal and the output pulsed RF. (See Figure 5 for a typical Pulsed Swept Measurement System.)

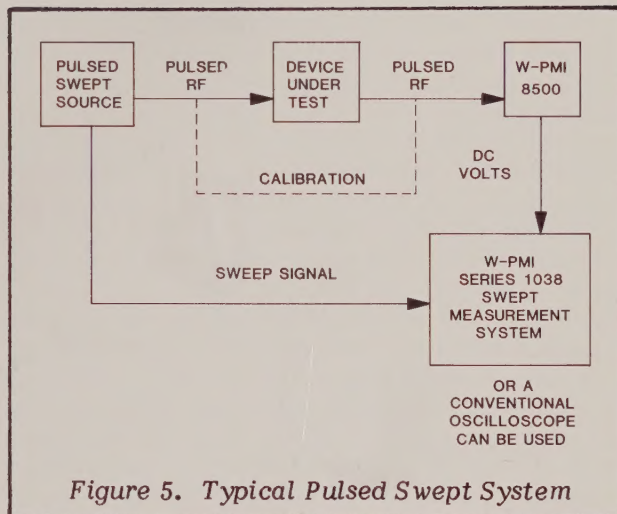


Figure 5. Typical Pulsed Swept System

The 8502 is operated with channel A attached to a coupler or power splitter at the input to the DUT, and channel B attached to the output through a coupler or attenuator if needed. The 8502 can be used to measure Input power and Output power at the same time, or to measure Gain/Loss using the A/B or B/A ratio function.

The amplifier can be tested using swept frequency techniques by adding a W-PMI Model 1038-NS20 or N10 system to the setup. For details on this technique, refer to W-PMI Application Note Number AN25, "Pulsed Frequency Response Testing".

Time Domain Multiple Access (TDMA) Systems and Frequency Agile Systems

TDMA systems are satellite communication systems that use one satellite to time share up to five customers. The time slots are usually multiples of 40ms. The slots are not the same for each customer, and will vary according to the customer's needs. Due to the random nature of the signal, the duty cycle will also be random. For this reason, it is not possible to use an Average Reading power meter to easily find the Peak Power. The Model 1018B Peak Power Meter has, and is, being used very successfully in this application. The Model 8501 and Model 8502 will also work very well. Since the Series 8500 is fully programmable, the meters can be

used in remote monitor locations.

Frequency agile systems have a very random power-on time, and usually the frequency is changed each time the power is turned on. The on-time is usually very short and measured in microseconds. The single pulse measurement capabilities of the 1018B, 8501, and 8502 are ideal for this application. In many cases the transmitting sites are in remote locations so the IEEE-488 interface capability of these meters can be used to provide a remote monitor. Another feature built into the Series 8500 is that the calibrator and the detector can be located remotely from the meter. If this is done, there is a change in the accuracy specifications that is a function of the distance separating the detector head and the meter. It is recommended that the factory be consulted to discuss these changes in relation to any specific application where the head will be remote from the meter.

APPENDIX A

AN AUTOMATIC CALIBRATION SYSTEM FOR DIODE POWER DETECTORS.

Appendix A will discuss an automated system for the calibration of low-barrier Schottky diode detectors used in microwave power measurements. This system was designed and developed by W-PMI, and has been incorporated as an integral function of the Series 8500 Peak Power Meters.

A computer-controlled calibrator circuit is employed to generate precise calibration data using a simple thermal power meter as a reference. This permits diode detectors to be used for absolute power measurements with the accuracy generally associated with thermistor power meters.

SYNOPSIS

Computer control of a calibration process for detectors used to make R.F. power measurements results in substantially improved accuracy, reliability and reduced life-cycle costs. A generalized description of the technique serves to illustrate the improvements possible using the capabilities of a microprocessor. In this case the microprocessor makes it possible to use a powerful technique that would otherwise be impractical. Specifically, the technique allows diode detectors to be used for microwave power measurements with the accuracy generally associated with thermistor power measuring devices. Diodes have the advantages in terms of speed of response and dynamic range. Due to the inherent non-linearity of diodes used as R.F. detectors their accuracy previously has not been as good as thermal power detectors. Using the computer aided calibration technique, precise calibration data are generated with a simple thermal power detector as a reference. The calibration is performed over a dynamic range in excess of 50dB while the thermistor reference is required to operate only over a modest 15dB range.

INTRODUCTION

At microwave frequencies, low-barrier Schottky diodes are commonly used in detector circuits

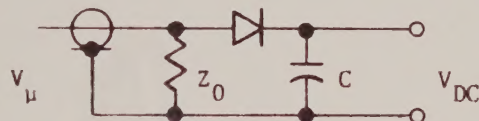


Figure A1a. Single Diode Detector

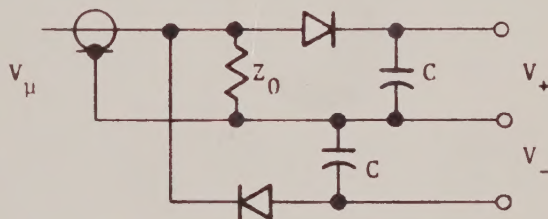


Figure A1b. Balanced Detector

such as those shown in Figures A1a & b for the rapid determination of power over an extremely wide dynamic range. However unlike thermal power meters, a diode's response is an inherently non-linear function of input power, i.e. for a diode detector with no external load resistance:

$$V_{DC} = \frac{nkT}{q} \ln \left\{ B_0 \left[\frac{qV_{\mu}}{nkT} \right] \right\} \quad (1)$$

where V_{DC} is the detected voltage, V_{μ} is the amplitude of the incident R.F. signal, $B_0(z)$ is a modified Bessel function of the first kind and n is the diode's ideality factor. A first order polynomial expansion for B_0 shows that the diode's response is square-law only at low power levels, requiring the detector to be calibrated over the majority of its dynamic range. Lesser effects are the diode parasitics and the frequency response of the detector and mount. In all respects there is a significant variation between devices, requiring individual calibration if accurate measurements are to be made. In

addition to the calibration uncertainties, the accuracy with which individually calibrated diodes may be used to determine microwave power is also limited by short and long term drift effects such as temperature and aging. Consequently, their accuracy has previously not been as good as thermal power detectors.

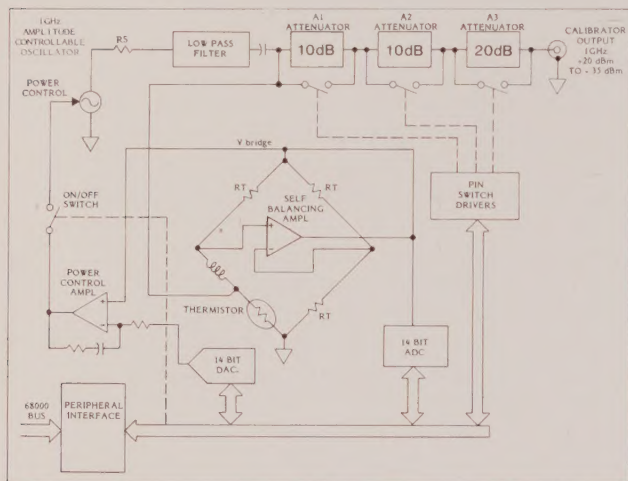


Figure A2. Block diagram of the 1GHz calibrator developed by W-PMI to calibrate detectors for RF applications. The characteristics of the electronically switched attenuators need be known only approximately as the processor uses the measurement detector itself to determine their relative effective attenuation (see the following discussion).

AUTOMATIC CALIBRATOR SYSTEM

The measurement of absolute power requires the diode's sensitivity to be corrected both for frequency and for the non-linearity of its transfer characteristic. However, in a well designed detector circuit the two effects are independent. Moreover, non-idealities in the frequency response are related to static parasitics in the detector assembly which are independent of aging provided the physical construction of the detector circuit is preserved. In contrast, the power response of the diode itself is effected by impurities introduced into the substrate during fabrication and by the interfacial Schottky junction having uncertain electrical properties. Despite a post-bake process used to stabilize

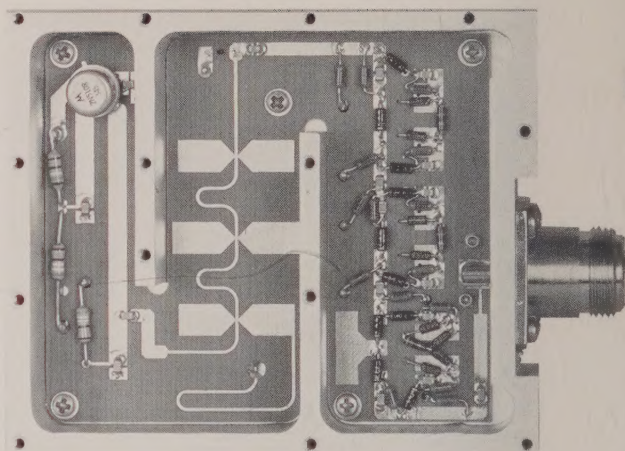


Figure A3. The oscillator assembly of the 1GHz calibrator used to linearize the diode detectors for pulsed RF measurement applications. The tuneable oscillator is at the left of the picture and the PIN switch attenuator is on the right. The thermistor reference is at the top, center of the picture, in the microstrip low-pass/band reject filter portion of the circuitry.

the junction, these latter effects are still sensitive to long term temperature cycling and aging.

The automatic calibrator circuit shown in Figure A2. was developed to eliminate measurement errors related to variations in individual detector diode's characteristics. The circuit permits detectors to be calibrated against a thermal reference prior to using the diode to perform measurements. A 1GHz. diode calibrator, shown in Figure A3, consists of a set of electronically switched attenuators and an oscillator whose output power is controlled using DC substitution in a thermistor reference. The thermistor levelled oscillator may be programmed to produce precise power outputs over a dynamic range of approximately 15dB. The oscillator signal is passed to the output through a matrix of three attenuators and PIN diode switches, extending the dynamic range of the calibrator by 40dB. For this purpose, the characteristics of the electronically switched attenuators need be known only approximately. A combination band-reject/low-pass microstrip filter ensures the output to have a spectral purity better than -50dBc. The circuit is constructed using convenient, packaged devices and com-

compensated using semi-lumped techniques. The entire calibrator circuit is sufficiently small and inexpensive to be included in commercial diode based power meters and measurement systems.

The thermistor standard is configured in a self-balancing bridge arrangement so that the R.F. power incident on the measurement diode is given by:

$$P_o = \alpha_i A_i \left\{ \frac{V_a^2 - V_o^2}{R_t} \right\} \frac{R_t}{R_o}, \quad R_o = 50\text{ohms} \quad (2)$$

where V_a and V_o are the quiescent bridge voltage and the voltage with R.F. power applied, respectively. R_t is the bridge impedance, A_i is the selected attenuation factor and α_i is a correction term accounting for attenuator imperfections and mismatch errors. Equation (2) shows that a knowledge of the ambient bridge voltage, V_a , and the bridge voltage with R.F. power applied, V_o , permits the microwave power dissipated in the thermistor to be calculated. Here, the thermistor bridge and tunable oscillator are configured in a closed loop feedback network and the operation is somewhat different. A 14 bit DAC is used to determine the ambient bridge voltage. The processor is then able to calculate a bridge voltage, V_r , which corresponds to a particular required output power, P_r , using a rearrangement of equation (2):

$$V_r = V_a^2 - \frac{R_o P_r}{A_i \alpha_i} \quad (3)$$

When this value is written to the 14-bit DAC the oscillator settles to give precisely the correct output power.

Thermistor bridges such as that illustrated in Figure A2 are significantly affected by ambient temperature drift. Here, co-ordinated control of the oscillator and calibration process allows the thermistor to be instantaneously zeroed prior to setting the power to the most sensitive levels. In addition, the thermistor leveling cir-

cuit is required to operate only over a modest dynamic range of less than 15dB. Table AA tabulates measured power outputs from the calibration port and illustrates the extremes of precision which can be achieved by the circuit.

A prerequisite of the calibration process is the ability to determine the correction factors, α_i , corresponding to each attenuator setting, A_i . An important aspect is that the mismatch uncertainty associated with each attenuator may be eliminated only if the effective attenuation is computed with the measurement detector connected to the calibration port. The measurement is performed by computing the relative effective attenuation of each range using the measurement detector itself to provide a (voltage) datum. Specifically, the relative attenuation of two attenuator ranges is calculated in the following manner:

The smaller of the two ranges is selected with the oscillator power set to an appropriate (low) level, and the detector voltage is measured. The larger of the two attenuators is then switched in and a higher power level is iteratively found (using an interval division algorithm) which produces an identical detector voltage to that obtained with the first attenuator selected. The relative effective attenuation is then obtained upon division of the two powers. In this way, the relative attenuations of all the ranges may be obtained with a maximum of resolution and hence minimum uncertainty. A single adjustment is incorporated to permit the calibrator to be standardized at a fixed (0 dBm.) absolute power datum. At this power level, the calibrator has an excellent source match (better than 30 dB), so that the standardization may be performed with a calibrated thermal power meter of known effective efficiency.

DETECTOR CALIBRATION AND USE

The apparatus described permits individual detectors to be easily and frequently linearised against the internal thermistor reference. In many circumstances, such as relative (or normalized) power measurements or six-port applications, no further information need be included in the calibration. However, in addition to the linearisation, the calibrator provides an absolute power datum at the calibration frequency. This can be combined with relative flatness

characteristics to permit accurate absolute power measurement over a broad band of frequencies. For this purpose, a Read Only Memory containing frequency response information might be included in the detector assembly.

The linearisation of the detector is achieved in the following manner. First, the effective relative attenuation of the switched attenuators is determined using the method described above. This allows the calibrator to perform a power sweep from -33dBm to +20dBm in a series of precisely controlled steps. At each step, the detectors voltage response is measured and recorded. This information is then inverted using a functional interpolation to provide a dense lookup table indicating power incident on the

detector as a function of measured voltage. The whole process is organized in such a way that gain and offset errors in the detector amplification instrumentation are essentially eliminated.

In operation, a detector voltage is interpreted by determining an appropriate lookup table ordinate and linearly interpolating between adjacent elements. The calculation is performed using fixed point binary arithmetic and requires less than 80 microseconds using an 8MHz MC-68000 processor. The result is a power measurement (expressed in either a linear or logarithmic scaling) which may be further manipulated according to the instrumentation or system requirements.

Table AA

The programmed power output of a 50MHz calibrator measured with a conventional thermistor-based power meter. The power measurement system had an uncertainty of $\pm 0.2\%$, and the maximum discrepancy between the readings is 0.43%.

Programmed power mW.	Measured power mW.	Difference %	Programmed relative attenuation dBr.	Measured relative attenuation dBr.	difference dBr.
11.8103	11.8135	0.03	+0.7925	+0.7937	-0.0012
9.8402	9.8402	-	0	0	-
5.5351	5.5451	-0.18	-2.4988	-2.4909	0.0079
3.1115	3.1180	-0.21	-5.0003	-4.9913	0.0090
1.7496	1.7553	-0.32	-7.5006	-7.4865	0.0141
0.9850	0.9887	-0.37	-9.9957	-9.9794	0.0163
0.5569	0.5594	-0.43	-12.4719	-12.4530	0.0189
0.3129	0.3137	-0.24	-14.9757	-14.9653	0.0104

TEMPERATURE COMPENSATION

Equation (1) shows that diode power detectors exhibit considerable temperature dependence in their transfer characteristics. Indeed, without any temperature compensation it becomes difficult to perform even relative power measurements with any accuracy. One common form of compensation is to resistively load the detector diode with an impedance which cancels the temperature sensitivity. However, such a compensation entails a decrease in the detector sensitivity and hence signal to noise ratio. Also, the compensation can only be made to work at one specific temperature and the performance degrades elsewhere. A more successful method is to temperature stabilize the diode. However, this is achieved at the expense of elaborate and inconvenient temperature stabilization equipment.

Temperature compensation of the detectors response becomes a less significant problem when using the automated calibrator described previously. Under most circumstances, the detector temperature during measurements is very close to the ambient temperature at calibration. Consequently, an unsophisticated approach is sufficient to accurately correct for the small (less than 10°C.) temperature changes normally encountered.

The temperature response of the detector is most significant at low levels where the sensitivity of an unloaded diode is indicated by:

Square
Law:

$$V_{DC} = \frac{nkT}{q} \ln \left\{ 1 + \frac{q^2 V_{\mu}^2}{4n^2 k^2 T^2} \right\} \approx \frac{qV_{\mu}^2}{4nkT} \quad (4a)$$

The diode has a weaker temperature dependence for incident power levels corresponding to the peak-detecting region:

Peak
Detection:

$$V_{DC} = V_{\mu} - \frac{nkT}{q} \ln \left\{ \frac{2\pi q V_{\mu}}{nkT} \right\} \quad (4b)$$

Equations (4a,b) may be expanded into rapidly converging series in differential temperature:

Square
Law:

$$V_{DC} = \frac{qV_{\mu}^2}{4nkT_c} \left\{ 1 - \frac{T-T_c}{T_c} + \frac{(T-T_c)^2}{2T_c^2} - \dots \right\} \quad (5a)$$

Peak
Detection:

$$V_{DC} = V_{\mu} - \frac{nkT_c}{q} \ln \left\{ \frac{2\pi q V_{\mu}}{nkT_c} \right\} \left[1 + \frac{T-T_c}{T_c} - \frac{nkT_c}{T_c} \left\{ \frac{T-T_c}{T_c} + \frac{(T-T_c)^2}{T_c^2} \right\} + O\left(\frac{\delta T}{T_c}\right)^3 \right] \quad (5b)$$

where T_c is the temperature at calibration. This suggests a temperature compensation of the form:

$$P(V,T) = P(V,T_c)(1+(T-T_c)(A(V)+B(V)(T-T_c)))$$

where $P(V,T)$ is the power incident on the detector, V is the detector voltage and T is the measurement temperature. The level dependent coefficients $a(V)$ and $b(V)$ may be obtained either by differentiating equation (1) with respect to temperature, or by calibrating at three different temperatures and solving the resulting simultaneous equations. The latter of these approaches has been found to give marginally better results, because it also compensates for temperature effects not included in the model. For an unloaded detector, the most significant of these is an internal parasitic resistance caused by impurities introduced into the substrate of the diode during fabrication.

When compensated in this manner, measurements performed with typical Schottky diode detectors have demonstrated an exceptionally low temperature dependence. The operation of the compensation scheme was verified by enclosing a detector in a temperature controlled environment and delivering power to it from a stable external source. Figure A4 shows the results of the experiment as the temperature was varied. The experiment was repeated at three power levels and the results represent a significant improvement in temperature stability over this limited range. In the event of a large change in ambient temperature or a requirement for maximum accuracy the detector may be easily recalibrated.

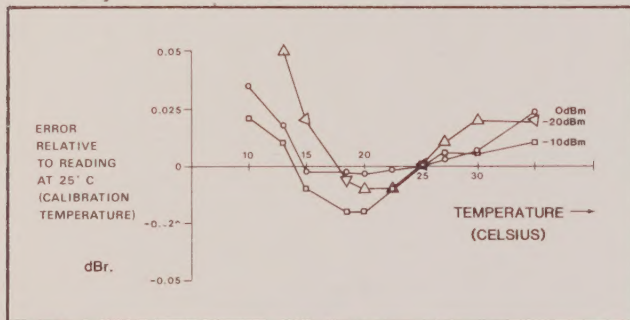


Figure A4. Temperature compensation of CW (unloaded) Schottky diode detectors relative to a calibration performed at 25° Celsius. Unloaded detectors exhibit a less well defined temperature dependence than loaded detectors because their properties are determined, in part, by imperfections in their fabrication. The temperature compensation method can also be applied to loaded detectors, which have a better defined (and larger) temperature dependence.

CONCLUSIONS

A system for the automatic calibration of diode detectors for use in microwave power measurements has been described. The system consists of a computer controlled calibrator circuit which permits the diode to be linearized against an internal thermal reference. On calibration, the detector and its related instrumentation is cycled through its entire dynamic range. A novel consequence is that the measurement equipment (incidentally) performs a complete self-test each time the detector is calibrated. The calibrator also provides a set (0 dBm) power datum at the calibration frequency which may

be combined with relative flatness characteristics to allow absolute power measurements over a broad range of frequencies. In addition, a temperature compensation scheme for diode power detectors is used to correct for small changes in ambient temperature. Large changes in ambient temperature may be readily handled by re-calibrating the detector.

The system has been used to calibrate both loaded and unloaded, single and balanced, diode detectors over increased dynamic ranges. Measurements performed with these calibrated diodes have demonstrated accuracies as good as commercially available power meters and substantially lower uncertainties.

References:

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